The Role of Object Representation in the Design of the Intelligent Radiology Workstation

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The paper describes the design of the Intelligent Radiology Workstation (IRW) that is intended to handle heterogeneous radiologic data (text, image, video) and radiologic knowledge in such a way that it is easy to store, access, use, and repurpose. An object-based structure is used to combine the relational database, hybrid knowledge base, and hypermedia within a common framework. Functions such as data entry and retrieval, browsing, and intelligent processing of data are available in the single environment. IRW open architecture allows radiologic digital resources to be used for clinical practice, diagnosis suppcrt, education, and research.

INTRODUCTION

Efficient organization of the modern medical setting depends on computer support that offers fast and easy access to an information resource for decision making and teaching. The need for passive information resources as well as interactive decision support tools led to the research on development of intelligent computer workstations [1][2]. The major limitation of the current computerized information resources is that they are available only through isolated applications that are incompatible in terms of hardware, software, and user interface environments. There is a need for unified information access and standards, and for application independent frameworks for delivery of medical information. The information resources should be separated from the organizational structure for viewing and interacting with them [3]. But at the same time, they must be integrated to facilitate the exchange of data and knowledge.

The goal of our research is to implement the Intelligent Radiology Workstation (IRW). IRW is intended to handle heterogeneous medical data (text, image, video) and complex medical knowledge and to manage information so that it is easy to store, access, use, and repurpose. IRW should facilitate cross-disciplinary activity by providing uniform standards for the exchange of information. To meet these objectives, computer technologies that are usually treated in isolation must be integrated within a single environment. IRW must provide tools to store data (databases); apply knowledge to data (knowledge based systems); interrelate information from different sources using different media (hypermedia); and use knowledge and inference to make retrieval and use of information easy. The use of the object representation paradigm allows combination of the database, knowledge base, and hypermedia into a framework for viewing all these technologies as parts of the IRW. The only requirement is that the object-oriented structure refers to all the data and knowledge representations within the IRW modules. This paper presents work in progress. We describe the way we are using object representation to build a uniform platform for IRW.

INTELLIGENT RADIOLOGY WORKSTATION DESIGN

Radiologic Object Representation

The fundamental feature that will make the IRW responsive to the user is it provides the user with an abstract data and knowledge model that closely resembles the user's model of the real world. The basic structural unit of the IRW is an object. When thinking about medical problems, we often think in terms of objects: of diseases, of diagnostic methods, of treatments. Moreover, when we think of a particular disease or syndrome, we think of it as a whole; data such as signs and symptoms, laboratory values, diagnostic procedures, treatment and prognosis are associated with it. Each medical domain approaches the same diagnostic problem using different diagnostic and treatment methods, and different classification patterns and semantics. Thus, medical objects are composite objects. They will have as many profiles as there are subspecialties that deal with a given medical problem. Our goal is to design a radiologic profile for medical objects that represents the radiologic image model. The radiologic image model (Figure 1) consists of:

A. ***Image data objects***:

1. Acquisition data
2. Real image data: pixel value, sequence, measurements portraying anatomical relations and chemical or physical processes that are associated with the patient state
3. Image-related data objects: look-up-tables, regions of interest, file formats
4. Image access data: procedures for storage and retrieval operations (methods indicating the location

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and the way to access physical data, how images are gathered within files, I/O operations and computer resources required to handle the image object, e.g. compression techniques).

B. *Non-image data objects*:

1. Domain-specific data objects: classifications, differential diagnosis, verbal descriptors for coding image content, image annotations for explanation/commentary
2. Clinically-related data objects: patient description, clinical history, indications for examinations

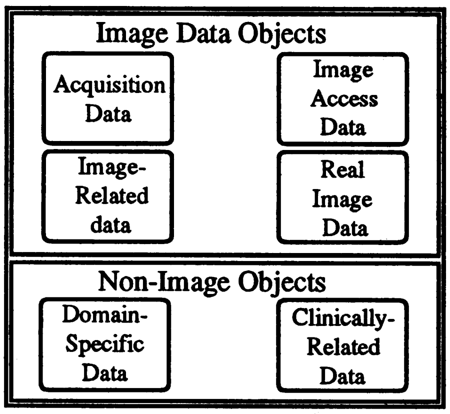

Figure 1. Structural Description of Radiologic Images

Database

The database forms the kernel of any information system. In the IRW environment, multiple databases will serve as sources of medical data, and the purpose of querying the system will not be predefined. IRW will manipulate independent data. The concept of data independence is simple; data should be stored in such a way that data is not specifically associated with any particular application. A relational database guarantees the independence of data. The basic data structure supported by the relational database is a table. Only one data item is allowed in any cell in a relational table (atomic data type). Objects in opposition to the atomic data type are structured data types. A relational database management system needs to be extended to allow creation of structured objects. A single object can possess several attributes (each is an atomic data type) as well as methods that manipulate the attributes. Objects are related by is-a-part-of links. Composite objects are defined as tree structures that are searched by recursively checking the relationship is-a-part-of until all objects making up a tree are identified.

Knowledge base

Knowledge-based systems separate the domain knowledge that is contained in the knowledge base from the general control knowledge that is mostly built into the inference engine. IRW knowledge base is a hybrid system that combines case-based reasoning (CBR) with rule-based technology. Each radiology subspecialty has its own rules and methods. Thus, there are multiple domain-oriented radiology knowledge bases in our system that are called the ***Case Bases***. The descriptive knowledge is kept in object hierarchies and relations, while heuristic knowledge is stored in rules. In addition to organizing knowledge in inheritance hierarchies, objects are also linked to rules. Rules are linked to the attributes of objects using attached predicates. Attached predicates allow the invocation of rules from within objects. Thus, in addition to attributes and their values within the object, there is separate information that refers to attached rules. The objects in the Case Bases refer to cases. Groups of cases are arranged in a hierarchy in which higher level cases represent prototype cases - classes, and lower level cases represent factual cases - instances (Figure 2). The initial search involves prototype cases and then expands to search through the factual cases to find the closest match. In this approach, knowledge of the domain used to structure and index cases supplements the information included in the cases themselves.

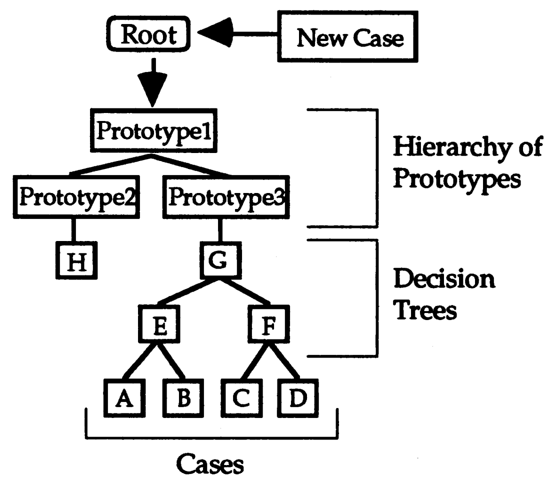

Figure 2. Case Hierarchy

For indexing purposes, we use a *hierarchical image description vocabulary* that is composed of basic observations and interpretations that form a continuum, in which higher level findings incorporate lower level findings [4]. Using this approach, the image details are coded using both basic observations such as the CT density of cerebral contents (e.g., appearance relative to brain tissue such as hyperdense, isodense, hypodense, CSF density, below CSF) and higher level findings that express interpretation of basic observations (calcified, blood, cyst, fat, etc.). The hierarchical ***Index*** communicates with the Controlled Vocabulary. The idea of using the finding-diagnosis continuum to describe medical images has been outlined by Greenes et al [5].

The structure of cases for a particular radiologic domain is kept in the domain-oriented Case Base, whereas the hierarchical Index is separate and is common to all the Case Bases in the knowledge base. Multiple radiologic Case Bases communicate with each other through the inference engine. The third component of the knowledge base is the Differential Diagnosis Manager (*DDM*) that is intended to use the Bayesian (probabilistic) network to compute the likelihood of diagnoses and generate lists of diagnostic hypotheses. Probabilistic networks have been applied successfully in the domain of pathological diagnosis [6].

Hypermedia

Hypermedia enhances the user interface in an important way. The ability to browse is generally the strongest reason for using hypermedia. Hypermedia can be browsed by following links, by searching the network for a particular string, keyword, or attribute value, or by navigating through a visual representation of the hypermedia network such as a map. The combination of hypermedia with a database and knowledge base needs to limit the freedom of direct browsing. IRW requires the capability to carry out structured searches. Within the IRW structure, the hypermedia system represents the Electronic Textbook of Radiology (ETR) [7]. ETR is capable of representing text, image, and sound; of representing concepts and relations between concepts; and of providing organizational structures. The nodes and links of ETR documents are mapped into graph-structured concept object spaces. ETR is composed of structural nodes representing text, picture, and sound, and nodes representing concepts (objects). Nodes include buttons that provide links (send messages) to other nodes and have scripts (methods) attached to them. Indexed nodes contain index terms, links that point to a definition of the concept represented by the index term, links that point to related terms or synonyms (links to the Controlled Vocabulary), and links that correspond to appropriate columns in relational tables that can be used to find documents that share a particular index term. The communication with the relational database provides a decomposition of the node (text document, image, sound file) into a set of index terms. A link to a particular column in the table is present if the corresponding index term describes the content of the document. This feature allows attachment of the radiologic thesaurus to the system and use of the Unified Medical Language System tools to map from the IRW vocabulary to another. ETR contains organizational and inferential links. Indexing links move the user from an indexed node to the corresponding index entry for that node. Is-a links indicate membership in a category, as in semantic networks. Has-a links describe the properties of nodes and are used to implement object-like capability. Rules are used to define links, implement predicate attachments on links, filter links, and execute actions.

Workstation Manager

Coupling a relational database with a knowledge base and hypermedia requires more than simply passing data through the import/export facilities of the cooperating systems. It requires an integration of systems and their behavior at each of several levels: 1) language level (syntax); 2) development techniques level (using database, knowledge based, and hypermedia techniques); 3) user interface level (allowing the user to interact with one system that has capabilities of each component and incorporates an explanation mechanism for the reasoning process); 4) concurrency control and recovery levels (protecting the multi-user environment, controlling concurrent accesses to the same knowledge base, providing recovery mechanisms for aborted queries).

The main role of the ***Workstation Manager*** is to structure atomic data from the database and to use the object-oriented data models of the knowledge base, and hypermedia, and link the relations expressed in the knowledge base and hypermedia to the relations expressed in the relational database (Figure 3).

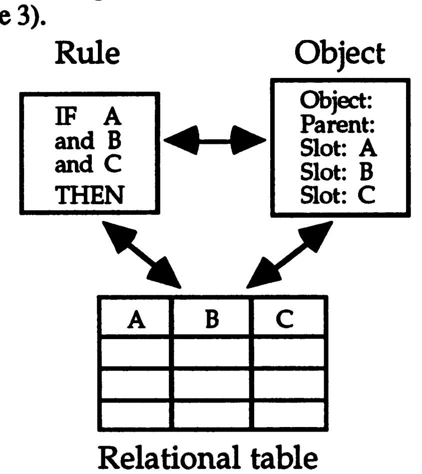

Figure 3. The relationship between logic, objects and the relational table

Mapping between objects and relations easily provides the inheritance feature, in which each relation can inherit attributes from its parent relation. The Workstation Manager recognizes the class objects represented in the knowledge base and hypermedia and brings records from the database to create instance objects. It needs to compose simple atomic items that are stored in the relation tables into the structured data items (objects). The Workstation Manager directs the search of the database, record by record, to return the next instance for the current object. The database system uses set-at-a-time retrieval compared with the record-at-a-time retrieval of hypermedia and the knowledge based system. Close integration between the knowledge based system, hypermedia and database requires an implementation of cursors on the database side that steps through a relational table one record at a time. These cursors provide access to necessary data stored in the database to be used by the Workstation Manager. Another function of the Workstation Manager is to apply knowledge to data through incorporated algorithms that identify and prioritize data according to chosen criteria. The Workstation Manager allows use of hypermedia in conjunction with a knowledge base through its indexing nodes and inference links. The Workstation Manager also assists in query formulation, as it permits the vocabularies of the user and the ***Controlled-Vocabulary*** of the system to converge prior to carrying out a search (Figure 4).

DISCUSSION

IRW is intended to support several goals: 1) Abstraction (the ability to have both decomposition and composition); 2) Modifiability (the ability to modify a part of the system without unexpected side effects in other parts); 3) Maintainability (the ability to make easy enhancements and adaptations); 4) Portability (the ability to have a system that is easily transferred from one computer system to another); 5) Reusability (the ability to reuse an existing code along with data and knowledge). The object-oriented system design promises to accomplish these goals.

Coupling existing computer technologies allows expert knowledge to be encoded in the same environment with a database and hypermedia system, so functions such as data entry, report generation, browsing, and intelligent processing of data are mixed together. The object-based metastructure allows integration of different computer technologies within one organizational framework. By developing hierarchies of objects (according to classification standards), we can describe medical problems in a more natural way than when using procedural approach. Inheritance creates possibilities for reusing the code. Domain-oriented class libraries can be flexibly used by different applications by assembling appropriate class objects drawn from the libraries. To access and assemble data for a specific application, the application must include the code that establishes the desired relationships among data. Although the application programs that access data stored within the relational database may evolve or change, this

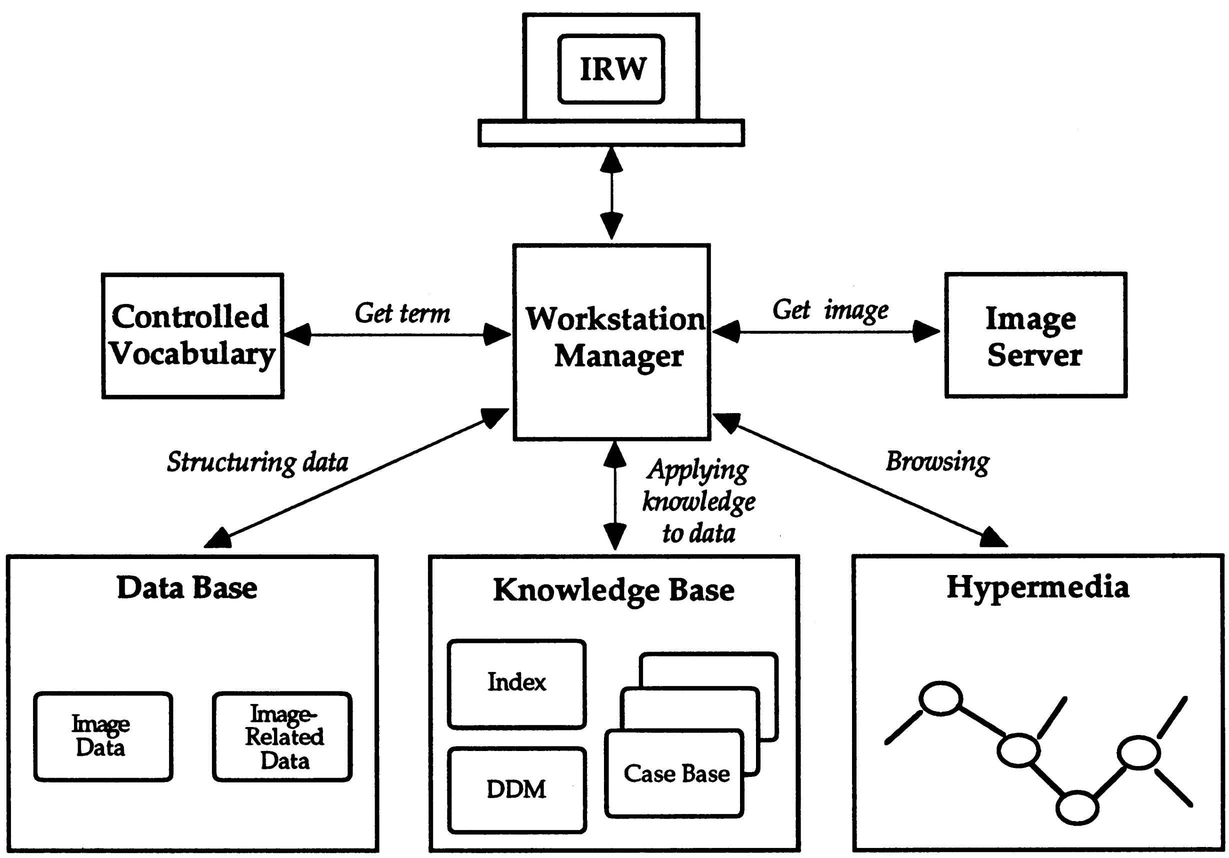

Figure 4. Intelligent Radiology Workstation Framework

possibility cannot affect the way the data is logically organized or physically stored. Most knowledge based systems have not incorporated database technology, which has resulted in systems in which knowledge is difficult to create, modify, merge, or export to other systems. Our design attempts to resolve this problem and avoid redundancy. The unified environment requires that an item of data be unique. Thus, although different applications refer to the same data, there is only one table that lists a particular data item and each data item is listed only once. Relational databases do not handle abstract data types and structured data items. The advantage of the extended relational database is that it structures atomic data and maintains the relational model, which gives data independence.

The extended relational model has been used to structure the *Digital Anatomist Browser* [8]. The use of multiple knowledge bases in conjunction with the relational database has been implemented in a feature dictionary, *MEDAS* [9].

Objects also provide a firm foundation for knowledge representation and inference. Integration of the relational database, knowledge base, and hypermedia permits the expression of complex queries and the use of content-based visual queries. For example, since each radiologic feature is identified by name in the knowledge base as well as by an image feature, it is possible to retrieve all images that contain a particular feature or a set of features. Our design does not incorporate automatic or semiautomatic feature extraction from the images. It offers a possibility of searching for images using verbal descriptors encoded into a *hierarchical index of radiologic findings*. Use of the knowledge base permits incomplete answers to a query that would have failed otherwise, or it can come up with a reasonable suggestion instead of returning "no data." We have chosen the CBR model for the knowledge base because reasoning from past experience resembles the way clinicians think through medical problems, and its underlying techniques refer to objects, attributes, and values. CBR also adds the algorithm that identifies the similarity between cases stored in the system and a new case that is being analyzed by the user. CBR techniques are especially useful in aiding decision making and teaching [10][11].

Hypermedia browsing tools interrelate information using various types of media and offer an excellent environment for quick assistance in clinical situations. The user may just browse the hypermedia system and select terms for subsequent queries. This approach ensures that the user understands the meaning of the terms and uses them in a way that the system also understands. Hypermedia is also a powerful educational tool. The concept of merging the browsing tool with the knowledge base to assist pathologists in the diagnosis of breast disease has been described by Heathfield et al [12].

Our system is currently in the implementation phase. The system is being written in the C++ on the Macintosh platform. Several steps remain to be completed before we can fully realize the contribution of the system design.

Reference

1. Swett HA, Fisher PR, Cohn AI, Miller PL, Mutalik PG. Expert system-controlled image display. Radiology 1989; 172(2): 487-493.
2. Giger ML, Doi K, MacMahon H, Nishikawa RM, Hoffmann KR, et al. An "intelligent" workstation for computer-aided diagnosis. Radiographics 1993; 13: 647-656.
3. Greenes RA. A "Building Block" Approach to Application Development for Education and Decision Support in Radiology: Implications for Integrated Clinical Information Systems Environments. Journal of Digital Imaging 1991; 4(4): 213-225.
4. Macura RT, Macura KJ, Morstad BD, Binet EF, Trueblood JH. Feature-Coded Image Database. In Boehme JM, Rowberg AH, Wolfman NT (Eds.): Computer Applications to Assist Radiology. Carlsbad, CA: Symposia Foundation, 1994; 313-318.
5. Greenes RA, McClure RC, Pattison-Gordon E, Sato L. The Findings-Diagnosis Continuum: Implications for Image Descriptions and Clinical Databases. In: Proceedings of the 16th Symposium on Computer Applications in Medical Care. New York, NY: McGraw-Hill, 1992; 383-387.
6. Heckerman DE, Nathwani BN. An evaluation of the diagnostic accuracy of Pathfinder. Computers and Biomedical Research 1992; 25(1): 56-74.
7. Binet EF, Macura RT, Macura KJ, Trueblood JH, Toro VE. Electronic Textbook of Radiology: Brain Mass Module. Supplement to American Journal of Roentgenology 1994; 162(3): 189.
8. Brinkley JF, Eno K, Sundsten JW. Knowledge-based client-server approach to structural information retrieval : the Digital Anatomist Browser. Computers Methods and Programs in Biomedicine 1993; 40: 131-145.
9. Nayemi-Rad F. A feature dictionary supporting a multi-domain medical knowledge base. Computer Methods and Programs in Biomedicine 1989; 30: 217-228.
10. Turner RM. Using Schemas for Diagnosis. Computer Methods and Programs in Biomedicine 1989; 30: 199-207.
11. Macura RT, Macura KJ, Toro VE, Binet EF, Trueblood JH, Ji K. Computerized Case-Based Instructional System for Computed Tomography and Magnetic Resonance Imaging of Brain Tumors. Investigative Radiology 1994; 29(4): 497-506.
12. Heatfield HA, Winstanley G, Kirkham N. A menu-driven knowledge base browsing tool. Medical Informatics 1990; 15(2): 151-159.